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California Water Boards' Framework and Strategy for Freshwater Harmful Algal Bloom Monitoring: Executive Synthesis

Jayme Smith
Martha Sutula
Keith Bouma-Gregson
Marisa Van Dyke

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California State Water Boards' Framework and Strategy for Freshwater Harmful Algal Bloom Monitoring: Executive Synthesis

Jayme Smith[1], Martha Sutula[1], Keith Bouma-Gregson[2], and Marisa Van Dyke[2]

[1]Southern California Coastal Water Research Project Authority, Costa Mesa, CA
[2]Surface Water Ambient Monitoring Program (SWAMP), State Water Resources Control Board, Sacramento, CA

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FOREWORD

The Water Boards' Surface Water Ambient Monitoring Program (SWAMP) has developed a framework (i.e., programmatic elements, approaches) and a strategy to develop and implement a Freshwater Harmful Algal Bloom (FHAB) Monitoring Program across the State of California. The comprehensive framework, which is intentionally not bounded by financial considerations, is intended to lay out a broad vision for an FHAB monitoring program that California can work toward building over the long term. A focused strategy provides a road map for implementing high priority elements in the near-term through the development of subsequent multi-year FHAB Monitoring Program Workplans. The intent is for Water Boards staff to use this strategy document to evaluate what is feasible to implement, given potential FHAB Monitoring Program financial and personnel resources.

This executive synthesis report presents a high-level overview of the FHAB framework and strategy for executive managers and non-technical audiences, focusing on six main recommended actions that the Water Boards and their partners should take to build California's FHAB Monitoring Program.

A companion technical report provides full background on the FHABs monitoring framework and a rationale and discussion for each of the six strategic (priority) recommended actions for implementation, which were identified through discussions with the technical advisory committee (TAC) and deliberations by State Water Boards staff. A copy of the full report, which includes multiple appendices, is available at: https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1141_FHABStrategy_FullReport.pdf. A fact sheet summarizing the main elements of the report was also produced and is available at: https://ftp.sccwrp.org/pub/download/DOCUMENTS/FactSheets/1141_FHABStrategy_FactSheet.pdf.

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Name	Institute	Working Group(s)		
		PM	RS	FS
Barbara Barry	Santa Ana Regional Water Quality Control Board	X		
Mary Bartholomew	North Coast Regional Water Quality Control Board	X		
Erick Burres	State Water Resources Control Board	X		X
David Caron	University of Southern California	X		X
Natalie Caulk	California Coastkeeper Alliance	X		
Hugh Dalton	City of Santa Cruz	X		
Timothy Davis	Bowling Green State University	X		X
Rich Fadness	North Coast Regional Water Quality Control Board	X		X
Mary Fiore-Wagner	Lahontan Regional Water Quality Control Board	X		
Susan Fricke	Karuk Tribe	X		X
Luke Ginger	Heal the Bay	X		
Jennifer Graham	USGS New York Water Science Center			X
Meredith Howard	Central Valley Regional Water Quality Control Board			X
Christine Joab	California Department of Fish and Wildlife	X		X
Raphael Kudela	University of California, Santa Cruz		X	X
Christine Lee	NASA Jet Propulsion Laboratory		X	
Mo Loden	Alpine Watershed Group	X		
Jennifer Maucher-Fuquay	NOAA Phytoplankton Monitoring Network	X		X
Jackie McCloud	City of Watsonville	X		
Steve Morton	NOAA Phytoplankton Monitoring Network	X		X
Carey Nagoda	San Diego Regional Water Quality Control Board	X		X
Tim Otten	Bend Genetics			X
Hans Paerl	UNC North Carolina			X
Shannon Quigley-Raymond	San Diego River Park Foundation	X		
Sarah Ryan	Big Valley Band of Pomo Indians	X		X
Blake Schaeffer	EPA		X	
Bridget Seegers	USRA/NASA Goddard Space Flight Center		X	
Beckye Stanton	CA Office of Env. Health Hazard Assessment			X
Michelle Tomlinson	NOAA		X	
Randy Turner	San Francisco Estuary Institute		X	
Lori Webber	State Water Resources Control Board			X
Joseph Westhouse	State Water Resources Control Board			X
Susie Wood	Cawthron Institute			X
April Woods	Santa Cruz County Health Services Agency	X		

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LIST OF ACRONYMS

AB	Assembly Bill
BSMP	Beach Safety Monitoring Program - AB 411
BOG	Bioaccumulation Oversight Group
CCCHAB	California Cyanobacteria Harmful Algal Bloom Network
CDPH	California Department of Public Health
Chl-a	Chlorophyll *a*
CIcyano	Modified Cyanobacteria index
CyAN	Cyanobacteria Assessment Network
EPA	United States Environmental Protection Agency
FHAB	Freshwater harmful algal bloom
FIB	Fecal Indicator Bacteria
HAB	Harmful Algal Bloom
MC	Microcystins
MERHAB	Monitoring and Event Response for Harmful Algal Blooms
MERIS	Medium Resolution Imaging Spectrometer
NARS	National Aquatic Resource Surveys
NASA	National Aeronautics and Space Administration
NGO	Non-governmental organization
NLA	National Lakes Assessment
NOAA	National Oceanic and Atmospheric Administration
PSA	Perennial Stream Assessment
RCMP	Reference Condition Monitoring Program
SCCWRP	Southern California Coastal Water Research Project Authority
SFEI	San Francisco Estuary Institute
SS	Special study
SWAMP	Surface Water Ambient Monitoring Program
TAC	Technical Advisory Committee
TMDL	Total maximum daily load
USDFW	United States Department of Fish and Wildlife
USGS	United States Geological Survey

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INTRODUCTION

Freshwater harmful algal blooms (FHABs), defined as an overgrowth of cyanobacteria or eukaryotic algae, occur throughout California inland waters. FHABs can produce toxins that can harm humans, dogs, livestock, and wildlife. High biomass of both toxic and non-toxic blooms causes odor, poor aesthetics, and a cascade of ecological effects including growth of pathogenic bacteria, clogging of fish gills and benthic habitats, low dissolved oxygen concentrations, and fish kills. Blooms can also result in negative socioeconomic impacts for surrounding communities.

FHABs are negatively impacting beneficial uses in California surface waters, including drinking water, recreation, tribal and cultural uses, agriculture, and aquatic life (Figure 1). The degradation of these uses has broad and sustained economic impacts. Nutrient pollution, hydromodification, and physical habitat alteration that occur through human activities are the principal drivers, exacerbated by climate change through warming, higher CO_2 levels, and changing precipitation regimes. However, little is understood about the extent of FHAB risks to core beneficial uses because many inland surface waters are not routinely monitored for these impacts. Severe and chronic FHAB impacts have been documented in communities in the Klamath River, Clear Lake watersheds, Central Coast, Central Valley, and Inland Empire, among others. Additionally, FHAB impacts compound other adverse conditions in economically disadvantaged communities, including limited access to recreational opportunities, clean water, adequate sanitary infrastructure, health care, and affordable and safe housing.

The State Water Board took initial steps in 2016 to respond to the growing problem of FHABs by developing a statewide long-term vision and strategic plan known as *The FHAB Assessment and Support Strategy*. This document called for development of a statewide FHAB monitoring program comprised of 1) incident response, 2) ambient monitoring, and 3) decision support.

Since 2016, the State Water Board and the Regional Boards (collectively, the Water Boards) have made strides in developing an incident response program and using remote sensed satellite data to identify FHABs, one of the core ambient monitoring approaches. However, the other ambient monitoring recommendations in the 2016 strategy, along with the decision support elements, have not been implemented to date due to lack of resources and a clear framework for implementation.

This document articulates the vision, framework, and strategy to develop and implement a statewide FHAB Monitoring Program (Figure 2). Implementation of the strategy will rely on the collective buy-in and contributions of multiple partners – beyond the Water Boards – that will be asked to coordinate, pool, and leverage resources effectively. If the various programmatic elements are implemented as recommended in this document, California will be optimally positioned to move decisively and quickly toward achieving a comprehensive, sustainable statewide FHAB monitoring program.

Ambient monitoring and incident response – which were originally called for in the 2016 FHAB Assessment and Support Strategy – are foundational approaches to implementing the FHAB monitoring strategy. These two approaches are supplemented by a third approach referred to collectively as special studies and research. All three approaches will be supported by the buildout and ongoing maintenance of FHAB infrastructure – an encompassing term that includes everything from training and SOPs to decision support, which is the third pillar of the 2016 FHAB strategy.

SWAMP has used the term “core beneficial uses” since 2010 as a strategy to consolidate the many beneficial uses that the Water Boards are charged to protect. The elements of this strategy are organized around addressing key management questions related to five core uses:

- swimmable (i.e., contact and non-contact recreation)
- fishable
- aquatic life
- raw water source protection
- tribal tradition and culture

Figure 1. From left to right: Top: Floating macroalgae in Loma Alta Slough, Oceanside, FHAB caution posting, harbor with cyanobacterial bloom. Middle: large cyanobacterial bloom in Clear Lake amidst kayakers, bloom of *Microcystis* at Legg Lake, benthic cyanobacterial mat in Eel River. Bottom: *Microcystis* bloom and dead fish at Clear Lake, cyanobacterial bloom in Silverwood Lake.

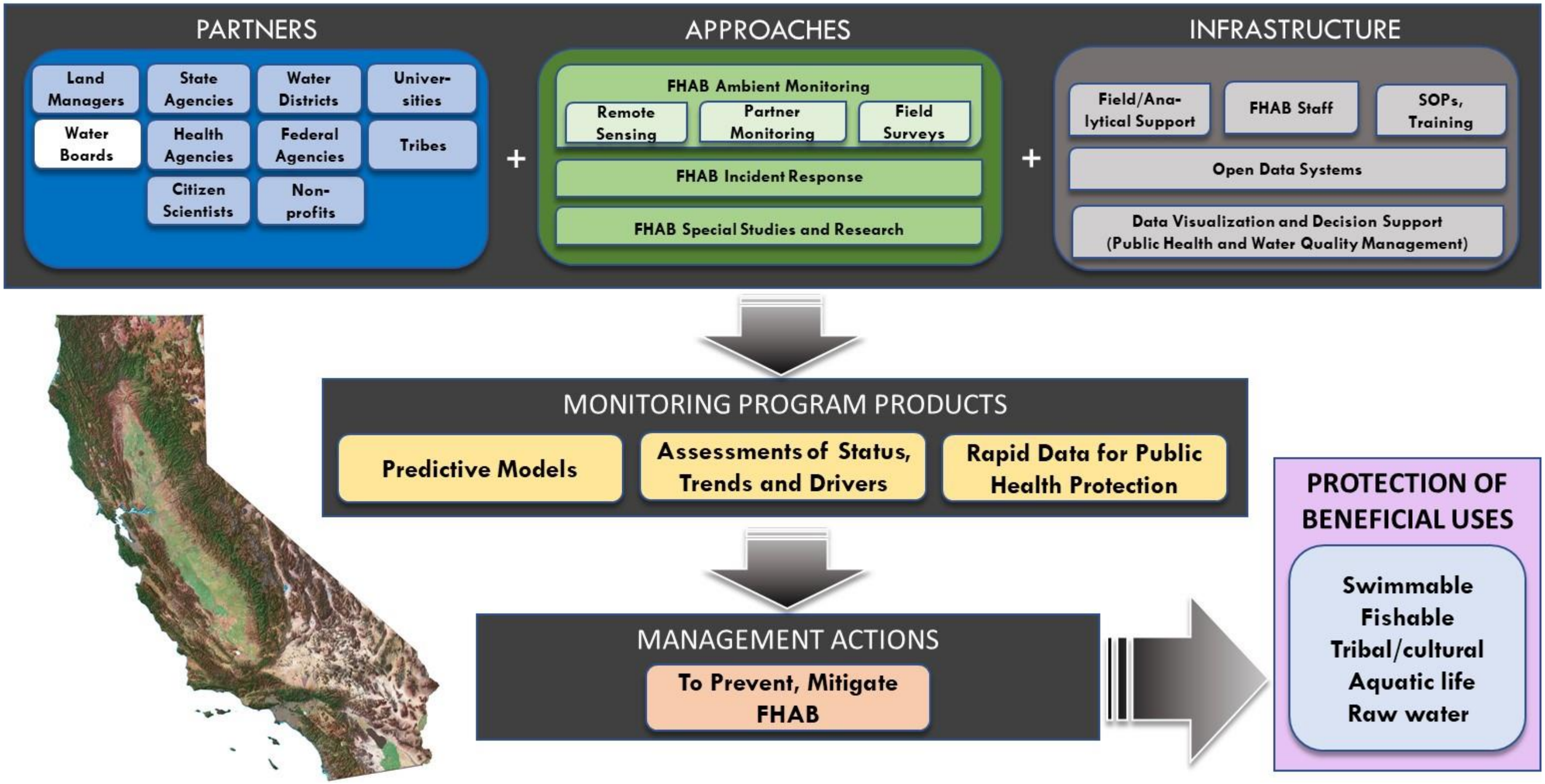


Figure 2. This schematic shows the major elements of the program, including ambient monitoring, incident response, and special studies (shown in green). These approaches are implemented by FHAB monitoring partners (shown in blue). Infrastructure to support the program are shown in gray. Collectively, these components produce assessments of FHAB status, trends and drivers, and predictive models of FHAB occurrence and drivers. This information is used in coordination with Water Board policies and programs to implement actions to prevent and mitigate FHABs. These actions will ultimately protect core beneficial uses: swimmable, fishable, aquatic life, raw water source, and tribal and cultural uses. SOPs = standardized operating procedures.

Management questions that formed the FHAB strategy are focused on immediate information needs to manage the impact of FHABs on water quality, including understanding the **status and trends** of FHABs, including the presence and concentrations of cyanotoxins, and the **environmental drivers** influencing FHAB magnitude, extent, frequency, and duration. Specific consideration is given to three waterbody types: 1) lakes and reservoirs, 2) streams and rivers, and 3) coastal confluences (i.e., estuaries, coastal lagoons, etc. directly influenced by river runoff).

A key strength of the monitoring strategy is its reliance on multiple approaches to collecting ambient FHAB monitoring data to inform management decisions that ultimately lead to better protections for public health and the environment (Figure 3). Specifically, the strategy integrates: a) a **partner program** that provides infrastructure to encourage FHAB monitoring by other federal, state and local agencies, tribal governments, citizen science groups, etc., b) **field surveys** developed and managed by SWAMP or its partners, and c) **remote sensing approaches** that build upon the current partnership that California has formed with federal agencies. Additionally, **incident response** will continue and will be strengthened via synergies with ambient monitoring approaches. Meanwhile, the strategy relies on **data management, visualization, and decision support** systems as a core part of the monitoring infrastructure necessary for managers to effectively use FHAB data for management decisions and timely communication to the public.

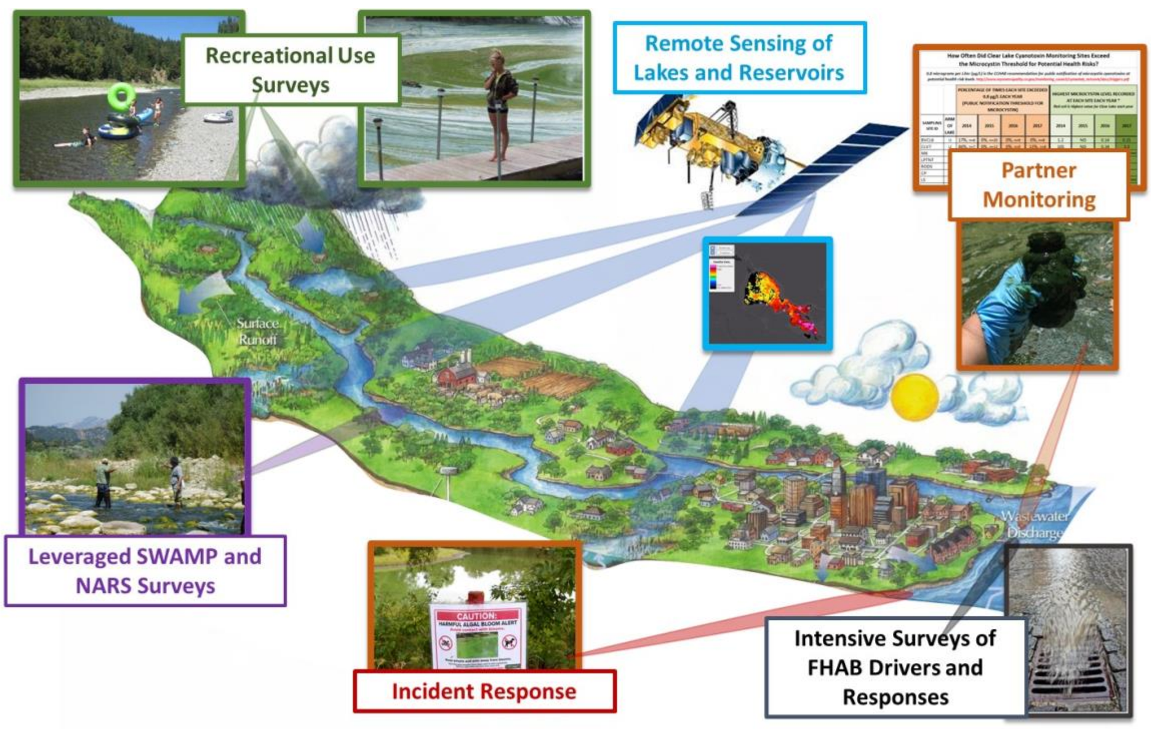


Figure 3. Different FHAB monitoring approaches provide complementary, cost-effective, and actionable data to protect public health and inform FHAB mitigation. For example, partner monitoring and recreational use surveys are done frequently enough to protect public health, but do not provide data on environmental drivers. Remote sensing, SWAMP and National Aquatic Resource Surveys provide data on the extent and magnitude of FHAB events but do not inform what is driving a problem in a specific waterbody. For that, intensive FHAB driver assessments are needed.

An FHAB monitoring program would not only benefit many other Water Boards' programs, but also other state and local agencies with mandates for protecting water quality and public health. Simply put, without the FHAB data that would be generated through this monitoring program, water quality and public health cannot be protected, and water bodies cannot be restored. The FHAB monitoring data also will be highly relevant and valuable to local, state, and federal governments, various community, stakeholder, and tribal groups with an interest in protecting the many beneficial uses that are being impacted by FHAB. Finally, it is important to note that while implementing a statewide FHAB monitoring strategy will not on its own prevent, control or mitigate FHABs, the monitoring program will generate the data necessary to inform management actions, as well as track changes in water quality following management actions.

Approach to Developing an FHAB Monitoring Program Vision and Strategy

Discussions with a Technical Advisory Committee (TAC) of national HAB experts, Regional Board HABs staff, tribal government, and citizen scientist monitoring leads, among others, produced a comprehensive vision for the programmatic elements, options, and recommendations that could form the foundation of an FHAB monitoring program that protects the core beneficial uses (Figure 4). Together, these approaches can address the multiple management questions and information needs that were identified, although the resources and staff required to implement all the recommendations have not yet been identified. State Water Boards staff considered the TAC recommendations for elements and program components for each of the approaches, then formulated a strategy that represents the incremental implementation of a subset of these options.

FHAB Monitoring Challenges

FHABs assessment is are challenging for many reasons:

- Multiple morphologies, species and toxins.
- Impacts to uses occur through many pathways that require unique monitoring approaches.
- FHABs and toxic events are predictable only with low accuracy, and highly variable in space and time.
- Impacts can occur far downstream from their point of origin.

The TAC considered these challenges in crafting the vision and elements of the FHAB program.

Because resources have not been identified, the strategy is flexible to scale with available resources and identifies the incremental timelines for development. State Water Board staff also designated each detailed implementation recommendation with (1) an associated timeline to implement the recommendation and (2) the estimated resource requirement level:

- TAC categories for implementation timeline: Immediate (0-2 yrs), Near-term (2-5 yrs), and Long-term (> 5 yrs)
- TAC categories for level of resources required: Low (< $200K), Medium ($200K-$1M), High (> $1M)

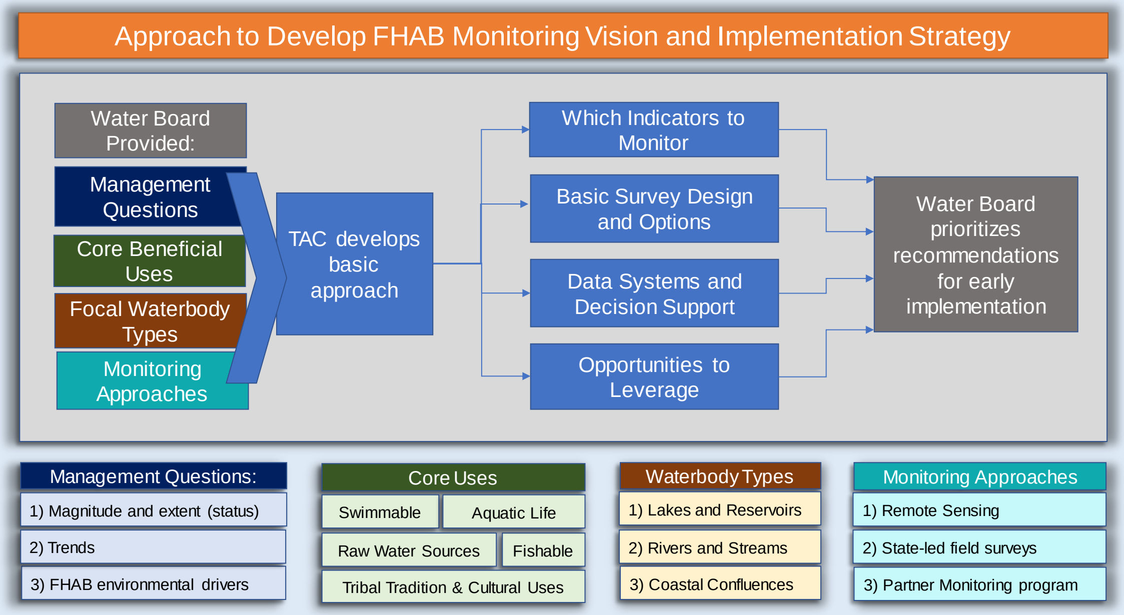


Figure 4. We developed the vision and elements of a comprehensive FHAB monitoring program with the help of a TAC. The visioning process produced many recommendations and will require more resources than what have been currently allocated. Water Board staff then identified the immediate and near-term priority building blocks to incrementally build an FHAB program.

Six Recommended Actions to Build an FHAB Monitoring Program

The monitoring strategy recommends six major priority Water Boards actions that should be implemented to build California's FHAB monitoring program:

1. Develop and implement an FHAB partner program;
2. Strengthen remote sensing program;
3. Implement field surveys to assess FHAB status focused on human health;
4. Conduct focused assessments of FHAB drivers;
5. Synergize incident response with ambient monitoring; and
6. Work to integrate HAB monitoring elements into all relevant Water Boards programs, permits, and policies.

The strategy recommends supplementing the above six recommendations with a strong program for public education and outreach to communicate risks and impacts of FHABs.

In formulating these priority six actions (and associated special studies), State Water Boards staff considered the TAC's recommendations for prioritized monitoring program components for each of the elements and actions examined. These six recommended actions (and associated special studies) collectively represent the strategic implementation of a subset of the approaches recommended by the TAC, including appropriate data systems and decision support tools in accordance with open data policies (see inset box: Open Data and Decision Support as a Core Principle).

Open Data and Decision Support as a Core Principle

- A core principle of California's FHAB monitoring program is the focus on management decision-making.
- "Open data" is a foundational principle for all current and future elements of the FHAB program and congruent with SWAMP data policies.
- Managers interviewed to discuss how the FHAB program could support their needs shared the difficulty in the use of current data systems to make management decisions on individual waterbodies or groups of waterbodies.
- Investments are needed in data visualization tools and functionality to enhance decision support for both public health protection and water quality management.
- FHAB partners recruited to monitor and submit their data will find greater incentive to participate if their data visualization and reporting can be addressed through FHAB decision support tools.

On the pages that follow are summaries of the six recommended priority actions, including tables that break out the estimated timeline to implement and the estimated cost to implement.

Recommendation #1: Develop and implement an FHAB Partner Monitoring Program

Development and implementation of an FHAB partner monitoring program is among the highest priority recommendations of this Monitoring Strategy (Table 1). The goal of this program is to promote and support local level FHAB monitoring efforts by establishing a shared monitoring framework and leveraging resources. This program is envisioned to involve the Water Boards as the primary coordinating agency with multiple partner entities that are each assessing specific waterbodies following a suite of standardized methods. Partners are envisioned to include tribes, local environmental health departments, parks departments, drinking water agencies, private waterbody managers, scientific non-governmental organizations (NGOs) and community science groups. A core principle of SWAMP is the strong encouragement and support of partner monitoring that leverages limited resources and improves stewardship of the State's watersheds. The merits of this approach are exemplified in the success of SWAMP's Bioassessment program, but currently no such partner monitoring model exists for FHABs.

Why Invest in a HAB Partner Program?

- California has some 189,454 stream miles, 14,000 lakes and reservoirs, and 400 coastal confluences; these waterbodies require frequent monitoring to accurately assess the potential risk of human and domestic animal health. The resources and logistics required for a state-implemented monitoring program of this scope would make it hard to implement. The Water Boards need partners to accomplish its goals.
- Building HAB monitoring expertise within local watershed management communities will strengthen stewardship of aquatic resources and is essential to help partners move in a common direction and accomplish healthy watersheds protection over time.
- Coordination and collaboration will collectively increase our collective institutional knowledge and capacity to respond to FHABs across Water Boards and partner agencies across the state.

The TAC agreed that recreational health (contact and non-contact recreation) is an immediate priority for this FHAB partner monitoring program. The steps to implement the program are outlined below (Table 1). FHAB partner monitoring is well poised to address FHABs due to the high frequency of data collection required for protection of recreational health at the beaches, swimming holes, and other aquatic recreational use sites found across the state. A fundamental tension exists between an idealized program to protect recreational uses and one that is affordable. FHAB partner monitoring provides an approach to balance this tension by collaborating with partner agencies to address the shared issue of FHABs. The partner monitoring effort, however, can and should be expanded to address other core beneficial uses as this program is meant to be adaptable to help support the interests and information needs of the partner group.

The FHAB Partner Monitoring program is designed with tiers to allow participants to customize their participation plan based on their available resources. Economically disadvantaged communities may require strategic investments to ensure they can participate, and strategies should be in place to ensure that all communities have access to this program. Both the low resource program tier and high resource program tier consist of indicators that are defined as **core indicators** and **optional indicators**. The core indicators vary based on the resource tier. The **lower resource tier program** has two key core metrics which are intended to be measured on a routine basis: a visual biomass assessment and microscopic assessment of toxigenic cyanobacteria community composition, while the higher resource tier program adds a third core metric: cyanotoxin measurements. Recreational health sampling is focused on shorelines of recreational beaches of all waterbodies including lakes, streams, rivers, or coastal confluence areas. The TAC recommended that sampling frequency could be adjusted based on the time of year in order to be cost-effective yet capture important events. The highest sampling frequency was recommended during prime recreational months, regardless of resource tier. For example, the prime recreational season statewide was identified as the period beginning two weeks before the Memorial Day holiday and ending two weeks after the Labor Day holiday. Within that period, the low resource program was recommended to sample a minimum of every 2 weeks. Due to this generalization, the TAC concluded that the spatial and temporal design elements cannot be overly prescriptive, and instead should allow flexibility to the diversity of potential waterbody types that are used recreationally.

Invest in Tribal partnerships for FHABs monitoring

Tribes are promising partners for FHABs monitoring. With mandates to protect the public and environmental health of their members, many tribes have robust water quality monitoring programs and are exceptional environmental stewards. Currently, there are 56 tribes monitoring water quality in California, though few include FHAB indicators. Beyond the spatial coverage of tribal data, it is of high quality with an established quality assurance plan for each monitoring project. Working closely with State and local agencies, tribal governments can help expand the resources available for FHABs monitoring. The addition of FHABs data collected by tribes into State databases would help fill data gaps for water bodies with minimal monitoring by other entities. Fewer data gaps provide better information to guide management decisions and improve water quality protection. Developing tribal partnerships should be central to all FHAB monitoring programs at the State, regional, and local scales.

The first step in program development is to decide on the scale and scope of the program, based on program goals and available resources. A key decision is the level of support for the Water Boards to provide to partners. At least three options are available, reflecting a range of resource investment from the Water Boards: 1) Provide training and standardized operating procedures, but no capital investments in equipment or analytical support; 2) provide training, some capital equipment and/or limited support for laboratory analytical costs; or 3) provide training, capital equipment and laboratory analytical support. The success of the program will also depend on effective data management, dissemination, and visualization, as partners who contribute their data will want rapid accessibility and relevant visualizations to analyze FHABs conditions in their watershed or region.

Table 1. Partner program development recommended actions, required special studies, associated level of resource investment and timing. Low resources: < $200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Resources Required	Specific Recommended Actions	Special Studies or Implementation Options
Immediate	Low	Identify scope, scale, and budget of FHABs partner program focused initially on recreational and fishable uses. Decide on what level of resource investment to support partner efforts is sustainable.	Recruit partner organizations, focused on tribes, communities of color, and economically disadvantaged communities.
	Low	Develop infrastructure to support the program, e.g., provide SOPs and sample design documents for partners, develop training modules. Engage with existing state/regional programs to pursue opportunities to incorporate FHAB indicators (see recommendation 3 of this chapter).	Develop FHAB recreational use monitoring protocols for shorelines, beaches, and wadeable rivers. Provide visual FHAB advisory trigger that fits into cyanotoxin based triggers, so data from Tier 1 groups can be used to issue advisories. Develop an algal condition index for lakes, reservoirs and estuaries and an FHAB specific component for routine application in waterbody assessment.
	Low	Inventory recreational and fishable use sites and identify where monitoring partners and interest already exist.	
	Low	Create data management and visualization infrastructure, including means and training for partners to visualize their data and that conforms with Open Data priorities.	Develop vision or workplan that scales with level of investment.
Near-term	Low	Recruit and train partners.	
	Medium	Dedicate staff at SB and RB to coordinate program.	
	Low-Medium-High	Continued funding of supplies and data management identified above.	
Long-term	Medium	Expand infrastructure for partner program to address other beneficial uses.	

As the infrastructure develops, dedicated staff at the State and Regional Water Boards will be necessary to coordinate the program and work with partners (among other duties). Resources will also be required to fund the equipment and laboratory costs associated with the scope and scale of the program.

In the long-term, the FHAB partner program can be expanded to assess the status and trends of FHABs as well as to begin to identify common FHAB environmental drivers. Assessment tools (e.g., thresholds and/or guidance levels) for other beneficial uses, such as fishable and aquatic life, are less well-developed. These other beneficial uses were identified by the TAC as a longer-term priority but should be developed as more risk indicators and thresholds are developed.

Recommendation #2: Strengthen the remote sensing program

Remote sensing is a cost-effective and complementary approach to field-based assessments of FHAB status, trends, and drivers. The Water Boards have already made strategic investments to capitalize on federally curated FHAB remote sensing products for large lakes and reservoirs; these data are provided through a California FHAB satellite portal. However, these investments, while among the first of their kind in the U.S., have not yet resulted in extensive use to address FHAB management questions or actions. **State Water Board staff recommend making strategic investments to strengthen California's partnership on remote sensing to capitalize on cost-effective and complementary information that it provides to field-based assessments of FHAB status, trends, and drivers (Table 2).**

Why Strengthen Remote Sensing Program?

- Remote sensing approaches are powerful since they can provide more comprehensive spatial and temporal coverage with minimal staff investment.
- Remote sensing of FHAB can be used as a screening tool for event response and ambient monitoring.
- It is the most powerful approach to assess FHAB status, trends and drivers in lakes and reservoirs, albeit with some limitations in management applications.
- Particularly when paired with partner monitoring data and/or event response data, this strategy element can support management actions in the immediate or near-term future with minimal financial investments.

Remote sensing acquires water quality data from satellite or other air-borne sensors (including aircraft and autonomous vehicles or drones). Satellite remote sensing is powerful in that it provides high-frequency temporal coverage at wide spatial scales, albeit with indicators that are limited compared to field-based approaches. Since 2016, California routinely acquires FHAB satellite remote sensing products from NOAA in collaboration with the current program with historic satellite data going back to 2002. These data can help estimate the presence and concentration of cyanobacterial bloom through an index called CIcyano (see full report for additional explanation). Other products include information on total algal abundance and water clarity. The data are served through a web-based tool managed by the San Francisco Estuary Institute (fhab.sfei.org), which visualizes the data from any of the 255 lakes currently captured by the satellite. The tool shows the CIcyano value for each pixel of the lake as a heatmap. Intended uses include: 1) an incident response tool in which waterbody managers could be notified if satellite imagery suggested that a bloom was developing, 2) use in ambient monitoring to assess the status and trends of FHABs in lakes and reservoirs that were visible via the satellite, and 3) as a decision support tool to help assess which waterbodies were a greatest risk for FHABs to prioritize them for a variety of management responses.

Data from this program are currently used primarily as a screening tool to provide an early warning that cyanobacteria are becoming dominant within a lake. The data that are currently collected are considered provisional since the reliability of CIcyano values within and across waterbodies is difficult to quantify. The tool, as it currently exists, can provide an early warning for managers to mobilize field crews to conduct a field assessment to track the potential presence and/or increase of cyanotoxins. Currently, satellite data within this tool are not actively being used to assess trends in CIcyano values over time, or for any water quality or water policy regulation, such as 303(d) listing or TMDL development.

Satellite imagery could be implemented more completely in the FHAB Monitoring Program for these uses with strategic investments, summarized in the Table 2 below, including:

- Standardized protocols and quality assurance and control documentation;
- Data communication, accessibility, visualizations, and reporting that can increase the utility of the program for the Water Boards and their partners; and
- Technological improvements that can greatly expand the number and completeness of waterbodies characterized.

An immediate priority is to use satellite data more broadly within the Water Boards. For this to occur, more data quality and assurance documentation for remote-sensed products are necessary. The Water Boards have already begun field validation to ground-truth satellite data and improve data quality characterization. This work should continue and be expanded, so that partners can help participate in field verification data collection and submit those data to a common database.

The Water Boards should partner with federal agencies to characterize the uncertainty associated with satellite data, then they can use the data to inform water policy and program decisions. To help in this process, data visualization and decision support tools should be created to efficiently provide Water Boards staff with relevant satellite data for their duties. These immediate investments will allow, over the long term, for routine use in monitoring and management decisions, including 305(b) reporting and as a supporting line of evidence in 303(d) listing.

Satellites provide one of the most consistent and longest time series of any type of water quality data. Water Boards staff have a pressing need to fill information gaps related to the status and trends of FHABs and to use these data to support management decisions. An immediate recommendation is to analyze the remote sensing data that exist for large lakes and reservoirs to determine trends, and environmental drivers of satellite metrics over the last 20 years.

Once the current data are more fully analyzed and used by the Water Boards, new data can be included to increase the number of remote sensed metrics that are calculated (e.g., chlorophyll-a) and the number of water bodies imaged by satellites. Data from the Sentinel-2 satellite could provide information on much smaller water bodies than the current Sentinel-3 data. It is recommended that the Water Boards develop a partnership with the federal CyAN Project to pilot and onboard new remote sensing products, such as Sentinel-2 data, that can expand the scope of lakes and reservoirs currently assessed (255) to nearly all the entire California resources (~14,000). All satellite data, both current and proposed, should be made open and available to Water Boards staff and the public. It is imperative to allocate resources to create functional data management and visualization systems to meet the goals laid out in the Water Boards Open Data Policy.

Table 2. Remote sensing program recommended actions, required special studies (SS), associated level of resource investment and timing. Low resources: < $200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Investment Level	Specific Recommended Actions	Special Studies or Implementation Options
Immediate	Low	Write report about data quality of remote sensed satellite algorithms for HAB detection.	Develop explicit protocol for using satellite imagery data as a supporting line of evidence in listing decisions.
	Low	Establish standardized protocols for routine analytical metrics for use in satellite analysis.	Standardize protocols and data visualization approaches to document frequency, extent, and magnitude of blooms using remote sensed data. Including ability to compare individual lake against summary stats at various spatial scales.
	Low	Conduct a status, trends and drivers assessment with current Sentinel-3 and MERIS satellite data (limited to lakes >160 ha).	Develop triggers that define the probability of exceeding *in situ* target chlorophyll-a or phycocyanin as a function of remotely sensed Chl-a (already funded).
	Low	Add existing metrics (e.g. Chl-a) to current database and increase accessibility of data to the public.	
	Low	Enhance data management and data visualization platforms to ensure open and easy access to data for staff and public.	
	Low	Continue and expand collection of data to ground-truth satellite data and improve data quality characterization.	Develop a strategy and SOP for satellite field verification, so that partners can help participate in collecting data and submit it to a common database.
Near-term	Medium	Incorporate Sentinel-2 data into routine use for lake and reservoir status, trends and drivers assessments.	Develop data infrastructure and analytical metrics for processing Sentinel-2 data and do a demonstration of status and trends for reduced geographic area.

Recommendation #3: Implement field surveys to protect human health

Human health impacts from FHABs include ingestion of toxins from contact recreation, dermatological impacts, aerosols and odors affecting non-contact recreation, and consumption of fish or shellfish contaminated with cyanotoxins. Field surveys based on a one-time field assessment can provide management actionable data and are most well suited to assessments at the statewide, regional or watershed scales. However, a key caveat is that these approaches cannot assess frequently enough to assure that public health in sampled waterbodies are actually being routinely protected, while remaining cost effective. This is a fundamental challenge of FHAB monitoring. **Implementation of state-led field surveys focused on protecting human**

health (see Table 3 below) is strongly recommended by the TAC. The data from these surveys need to be communicated in a timely and informative way and the public can then make informed decisions about when and how they recreate and fish.

Why Implement Field Surveys Focused on Human Health?

- Global climate change and local activities are combining to create an unprecedented risk of FHAB to human health through recreation, fish/shellfish consumption, and drinking water.
- High frequency sampling is needed to adequately characterize risk to recreational uses.
- Fish and shellfish tissue sampling are needed where FHAB are a chronic risk to inform fish consumption advisories.
- Field survey data support actions such as: 1) public health advisories, 2) 305(b) report and decisions on 303(d) listing, and 3) briefings for Legislature and State Water Board.

The Water Boards need to first determine the key management needs from the survey, then the scale and scope of the survey, as ambient monitoring on relevant timescales on a statewide level is impractical due to logistical and financial constraints. Resources can be maximized by leveraging pre-existing programs, such as the Beach Safety Monitoring Program – AB 411 (BSMP (AB 411)) and the Inland Beaches Workgroup under the Safe-to-Swim Network. Inclusion of FHABs monitoring in these programs would create a more holistic assessment of recreational water quality by incorporating more indicators into water quality risk assessments. If frequent monitoring is not possible, then monitoring prior to holiday weekends (e.g., Memorial Day, Independence Day, and Labor Day) is recommended, so that recent data are available to assess recreational risk for these high-use weekends.

Fishable field risk assessments would fill many data gaps about the exposure risks to cyanotoxins from fish and shellfish consumption in California. The Bioaccumulation Oversight Group (BOG) performs statewide fish tissue sampling and adding FHABs indicators to the sampling could be considered. Because cyanotoxins have been detected in coastal shellfish but are not routinely monitored by the CDPH Marine Biotoxin program, it is recommended that the State Water Boards works with CDPH to develop cyanotoxin indicators for marine monitoring. A fishable field survey will also require special studies to create consumption advisory thresholds and trigger levels.

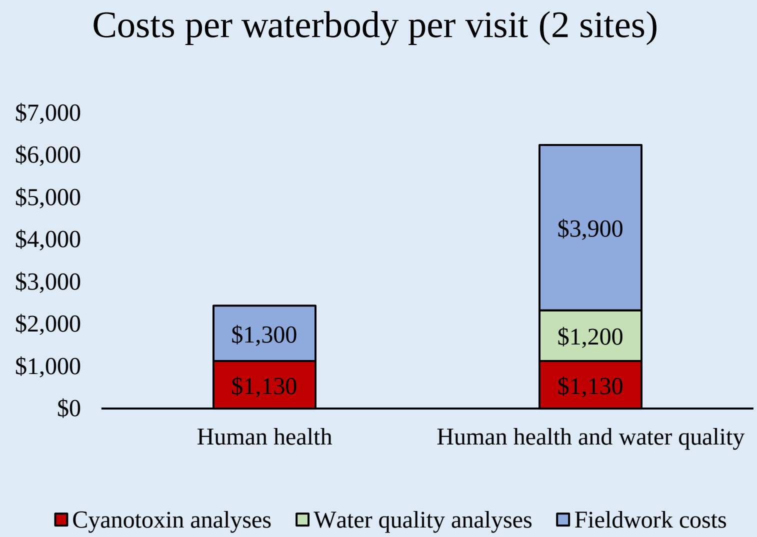
The TAC prioritized recreational and fishable beneficial uses, though in some watersheds or regions, other beneficial uses could be prioritized, e.g., Tribal Beneficial Uses. Additionally, Regional Boards could implement regional or watershed scale surveys for high-priority waterbodies. For each survey, multiple special studies will be required to determine the optimal leveraging opportunities and arrangements to protect public health. Due to the investments required to conduct state-led surveys, the management needs addressed by these approaches must be carefully considered before selecting the leveraging options to pursue, and the spatial and temporal designs when developing the FHABs field survey (see **Example of cost estimate for two monitoring scenarios**).

Table 3. Recommended actions required special studies, associated level of resource investment and timing associated with implementation of field surveys protective of human health. Low resources: < $200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Investment Level	Specific Recommended Actions	Leveraging Opportunities	Special Studies or Implementation Options
Immediate	Low	Modernize and incrementally build databases that house FHAB "public health" incident response and recreational and fishable use.		Develop the vision, including key data sources, data visualizations and GUI interface functionality, for each type of decision support, through interactions with intended user groups (targeted FHAB program partners).
	High	Implement a recreational use survey in collaboration with FHAB partners.	BSMP (AB 411) monitoring enclosed beaches (through partnership with local health agencies). Inland Beaches Workgroup integrated with Safe-to-Swim Network assessing FIB and HABs.	Decide on partnership approach, spatial and temporal design elements of recreational use survey, guided by Water Boards management priorities. Develop triggers for benthic cyanotoxin exposure and effects on human and domestic animal health. Consider incorporating the current FHAB pre-holiday assessment as part of the field-survey. SS on viability of leveraging BSMP (AB 411) to monitor enclosed beaches at coastal confluences. Design state-led component of the survey to fill in data gaps not provided by any partner data.
	Low-medium	Conduct FHAB fishable assessments where existing data point to chronic blooms.	Bioaccumulation Oversight Group (BOG) partnership to conduct FHAB tissue analyses in recreational lakes currently being assessed for mercury contamination.	Conduct literature review and sampling effort on cyanotoxins bioaccumulation and depuration for species caught in subsistence & recreational fishing for lakes and reservoirs, streams and rivers. Develop protocols to post cyanotoxin fish advisories based on incident and recreational use FHAB monitoring.
	Medium	Conduct coastal confluence FHAB tissue monitoring (commercial aquaculture and other partner sites).	CDPH partnership to add cyanotoxins to marine shellfish biotoxin analytical suite.	SS to determine utility and cost-effectiveness of partnership with CDPH on marine biotoxin monitoring. Develop a SOP for FHAB fish and shellfish biotoxin monitoring including analytical methods, standardized data transfer formats and training modules (partially funded through Kudela MERHAB study).

EXAMPLE OF COST ESTIMATE FOR TWO MONITORING SCENARIOS

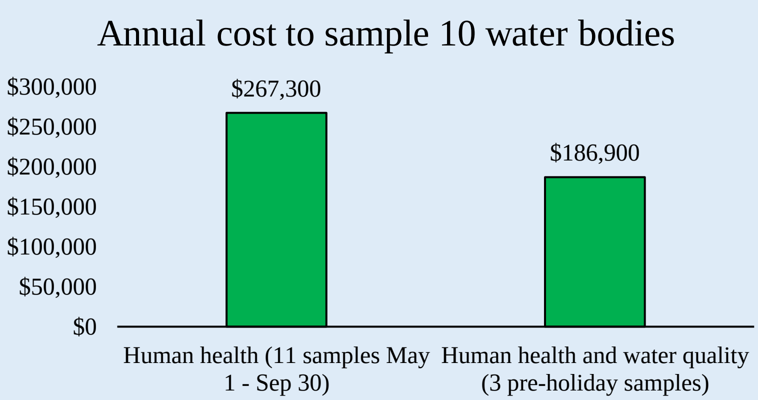
To quantify the costs of different monitoring options presented in this strategy, two lake monitoring scenarios were selected and used to estimate some of the 2020 costs of these programs.



Estimated costs to sample the first site per waterbody for human health and water quality sampling. Larger water bodies may require sampling at more than 2 sites.

Scenario 1: This scenario focuses solely on human health indicators with higher-frequency sampling every 2 weeks for 5 months of the year (similar to the design of BSMP (AB 411)).

Scenario 2: The human health and water quality scenario collects data to inform correlative environmental drivers assessments as well as human health risks. This scenario involves sampling 3 times per year, prior to the major summer holidays (Memorial, Independence, and Labor Days).



Cost to monitor two sites at 10 water bodies. Adding additional monitoring sites at a waterbody would be necessary for larger water bodies or water bodies with many recreational beaches.

Fieldwork costs are estimated to account for about 50% of FHAB monitoring costs (compared to 40-70% of the total per site cost for the BOG program and 56-65% for the PSA program). Any field-work partnerships to reduce the cost of field sampling to the Water Boards would expand the number of sites that the FHABs monitoring program could survey. More details on estimated costs are in Appendix 7 or here.

Recommendation #4: Conduct focused assessments of FHAB drivers

> **Why Conduct Focused Assessments of FHAB Drivers?**
>
> - Regional Board staff frequently receive calls about FHAB blooms and questions about what the Water Boards are doing to deal with them.
> - Status and trends monitoring can assess the magnitude and extent of the FHAB problem across California waterbodies, but only assessments of drivers provide information about what policies, programs and waterbody-specific actions are needed to mitigate HABS.
> - The most important landscape and waterbody scale drivers of FHABS will vary from watershed to watershed, so solutions must be customized.
> - Waterbody, watershed or regional scale integrated assessments of FHAB drivers and responses are time and resource intensive but produce information that are the most likely to result in a management action.

Answers to FHAB monitoring questions inform different types of actions, so the intended use of the information influences the spatial and temporal scale of monitoring and the approach required. For example, a manager at the State Water Board may want to know what the top priorities should be for policies and programs that could effectively reduce the risk of HABs across a region or state. To answer these types of questions, assessments of drivers at the statewide or regional scale are used to characterize a broad gradient of FHAB environmental drivers and responses. Because of expense inherent in a broad spatial scale, low-frequency sampling is integral to these designs, but often mischaracterizes toxic FHAB risk. At a watershed scale, a Water Boards staff may want to understand how certain sources or land uses may be associated with FHAB problems in order to do very targeted source tracking and catchment specific interventions. A lake manager may want to know the specific environmental drivers of FHABs in a certain waterbody in order to decide what management actions would minimize the risk of their occurrence in the future. Waterbody, watershed, or regional scale integrated assessments of FHAB drivers and responses are time and resource intensive but produce information that are the most likely to result in a management action.

To address the management information needs at all scales, **use of existing field survey data and remote sensing is recommended to conduct a statewide status and drivers assessment and to screen watersheds for FHAB risk** (see recommendation #6 on decision support)**, then fund intensive FHAB assessments at these high priority and higher risk watersheds or waterbodies (see details in Table 4 below)**. Existing remote sensing of large lakes and reservoirs and existing SWAMP programs such as the Perennial Stream Assessment (PSA), the Reference Condition Monitoring Program (RCMP), and the National Lakes Assessment (NLA) capture the majority of recommended FHAB responses and drivers, albeit with low frequency. They represent an important leveraging opportunity that can be used to assess the status and trends of FHABs statewide. These same data can be used to develop statistical models to predict risk of FHAB occurrence in unmonitored watersheds and waterbodies. Intensive FHAB assessments are needed for these high priority and higher risk watersheds or waterbodies. Continuous monitoring using buoys and platforms equipped with recording sensors (e.g., Chl-a, DO, pH, temperature) are especially appropriate for these targeted studies of drivers, especially in “hot spots” known to have frequent FHABs. All existing FHAB data and predictive models can be used to prioritize these more intensive assessments. Collectively, our understanding of FHAB risk environmental drivers will improve over time as data gaps are addressed.

Table 4. Field survey to defined FHAB drivers leveraging opportunities and recommended actions, required special studies, associated level of resource investment and timing. Low resources: <$200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Investment Level	Specific Recommended Actions	Leveraging Opportunities	Special Studies or Implementation Options
Immediate	Low	Use remote sensing, PSA, RCMP, and NLA (and other partner data) to generate an FHAB status and driver assessments of wadeable streams, lakes, and reservoirs.	Augment type of FHAB data generated through other SWAMP surveys (PSA, RCMP and regional partners) or NARS assessments.	SS to consider adding or modifying FHAB-relevant indicator protocols and sampling to PSA, RCMP and BOG programs. Develop protocols to implement molecular indicators in lakes and reservoirs.
	Low	Conduct FHAB landscape screening assessments to identify watersheds where more intensive FHAB assessments should be conducted.		Develop predictive FHAB models for wadeable streams and lakes and reservoirs (beta versions already funded).
Near-Term	High	At high priority locations, conduct intensive FHAB status and driver assessments at regional, watershed or waterbody scales.	Consider cost-sharing for FHAB intensification of regional board SWAMP “rotating basin” or “rotating waterbody” assessments.	

Recommendation #5: Strengthen incident response program

Incident response is a core component of the FHAB Monitoring Program. Even as ambient monitoring increases, the Water Boards will still need to respond to the public reports of blooms. Public observations of conditions at waterbodies statewide are more frequent than that of Water Boards staff and partner agencies. The members of the public who provides these incident reports should be considered a partner to the Water Boards who can ultimately provide more surveillance than ambient monitoring can feasibly provide. **It is recommended that incident response efforts should continue, and procedures be improved to harmonize with ambient monitoring and efficiently respond to FHAB reports from the public (see Table 5).**

Why Incident Response?

- Incident response efforts serve a distinct purpose of being able to respond to public reports of FHAB events.
- California has some 198,000 miles of rivers and streams, 14,000 lakes and reservoirs, and 400 coastal confluences that are not routinely monitored. Incident response is a key component to protect public health while funding of FHAB monitoring statewide is not yet sustained.
- Public reports are more likely to occur in economically disadvantaged and communities of color, so neglecting this program introduces inherent environmental justice issues.
- Climate change will exacerbate FHABs, so need for incident response is greater than ever.

Incident response efforts should continue, and procedures improved to efficiently respond to FHAB reports from the public. Incident response sampling is conducted to inform appropriate recreational health advisories and the sampling can reoccur numerous times to inform advisories until the bloom dissipates, these short or often long-term assessments can produce water quality data at an individual water body many times per year. Procedures for incident response sampling should be harmonized with the SOPs and approaches for ambient monitoring to ensure data comparability across all FHAB programmatic elements.

Table 5. Incident response recommended actions, leveraging opportunities, associated level of resource investment and timing. Low resources: < $200,000, medium: $200,000-$1,000,000, high: > $1,000,000.

Timing	Investment Level	Specific Recommended Actions	Leveraging Opportunities
Immediate	Low	Continue to fund incident response, including need for staff to conduct adequate rapid response and follow-up.	
	Low	Improve data management and visualization of incident response data to improve public communication and agency staff use of FHABs data.	Modernized webpage and interactive maps to better communicate to the public the HABs condition at water bodies.
	Low	Harmonize SOPs with those developed for the FHAB Partner Program	
	Low	Strengthen collaboration with other agencies to respond to bloom reports	Strengthen collaboration with other state agencies identified in AB 834
	Low	Assurance that incident response data are utilized in Water Board programs, actions and policies	

Recommendation #6: Work to integrate HAB monitoring elements into all relevant water board programs, permits, and policies

Issues regarding FHABs are interconnected with other fundamental water quality issues. In particular, FHABs are strongly linked to eutrophication, climate change, hydromodification, land use change that can alter physical habitat, chemistry, temperature, and light regimes. Thus, FHAB issues crosscut a number of Water Boards policies and programs (Figure 5). **It is recommended that a specific and concerted effort be made by FHAB and other Water Boards staff to link FHAB elements to all applicable programs wherever possible for a more holistic approach to assessing, managing, and preventing FHAB issues. This includes decision support to facilitate use of FHAB data for management decisions (Table 6)**

For example, FHABs are fundamentally a eutrophication problem that has a strong linkage to biostimulatory[1] objectives through a shared set of indicators; ultimately, biostimulatory numeric targets or objectives can serve as evaluation criteria for FHAB monitoring program data. Data from the FHAB monitoring program can serve as the basis to evaluate biostimulatory impairments of beneficial uses.

[1] Biostimulatory refers to the substances and conditions that cause an accelerated accumulation of organic matter (eutrophication), with a cascade of ecosystem effects, including HABs.

Table 6. Examples of Decision Support Implementation Recommendation Actions, Required Special Studies, Associated Level of Resource Investment and Timing to Support Water Boards Programs. Low resources: < $200,000, medium: $200,000-$1,000, 000, high: >$1,000,000.

Timing	Investment Level	Specific Recommended Actions	Special Studies or Implementation Options
Immediate	Low	Create tools for data analysis and visualization for Water Boards staff to use HABs data in water quality, drinking water, and water rights programs and policies.	
Near-term	Medium	Incrementally build publicly available data visualization tools, using an open source approach such as R shiny apps to encourage community development of such functionality	Develop predictive FHAB response models for lakes and reservoirs (remote sensing and field data-based) and wadeable streams (funded and in progress)

SUMMARY: AN INTEGRATED VIEW OF MONITORING PROGRAM OUTPUTS AND ANTICIPATED OUTCOMES

In California, toxic FHABs have been a recurring and escalating threat to public health, domestic pets, and other treasured beneficial uses. Climate change is already exacerbating these threats. With the projected increases in temperature, FHABs will worsen significantly over the next several decades. California is currently ill-poised to respond to these threats because FHABS are not routinely monitored and management actions are hampered by lack of data. FHAB monitoring is challenging because of multiple morphologies, species and toxins, the impacts to uses occur through many pathways that require unique monitoring approaches, FHAB events are highly variable in space and time, and the impacts to beneficial uses can occur far afield from their point of origin.

This strategy proposes six recommendations to cost-effectively characterize FHABs and confront these challenges and implemented with a strong program of public outreach and education. Taken together, multiple monitoring approaches provide complementary, cost-effective, and actionable information to protect public health and mitigate FHABs (Figure 5). Investments must be made across all approaches for California to achieve its goal of public health and beneficial use protection. Our proposed strategy is scalable to available resources and can be used to incrementally fill these data gaps on FHABs over time and engage the public.

The anticipated outcomes of this proposed FHAB monitoring program are several-fold, including:

1. Strong collaborative partnerships that adopt a shared set of standardized practices and information through open data systems,
2. Data visualization tools that enhance decision support,
3. Science products that can address key data gaps,
4. Support for partner and Water Board management actions and policies.

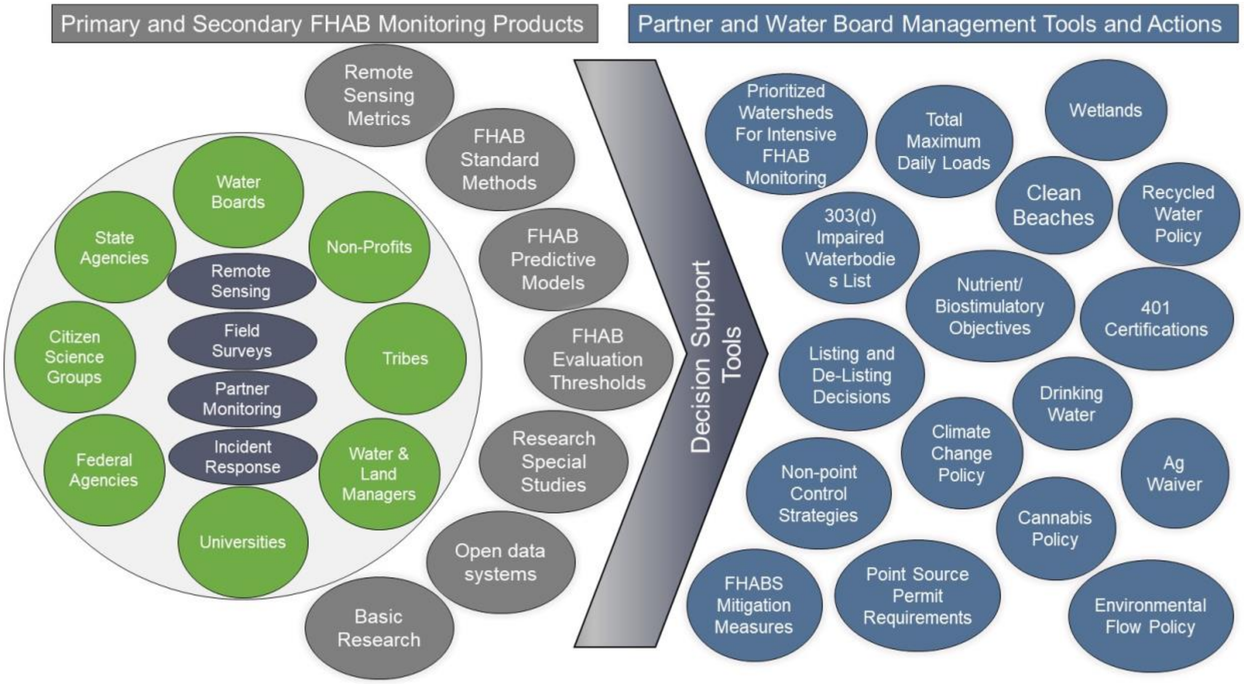


Figure 5. Illustration of relationship between FHAB core monitoring approaches (remote sensing, ambient field surveys, conducted by both the Water Boards and partners, and incident response), how these are applied by the Water Boards and their partners to yield the technical tools and products (featured in orange). These data and products are served through decision support tools to a variety of audiences including the public, land owners and management agencies. Their use of this information can result in a number of different programmatic tools, actions and policies. Adapted from P. Ode (Bioassessment Program Products and Related Tools, Action and Policies).

In making these investments, State Water Board staff stress that funding monitoring doesn't prevent, protect from or mitigate HABs, but provides data to inform it, and allows managers to track the progress resulting from implementation of HAB prevention and mitigation actions.

To reiterate, the report provides a comprehensive and visionary list of FHAB monitoring options for the Water Boards to consider; it is not designed to consider financial constraints or potential program budgets. This document positions Water Boards staff to evaluate what can be implemented given potential FHAB Monitoring Program financial and personnel resources, and to ultimately develop subsequent multi-year FHAB Monitoring Program Workplans that pave the way for phased implementation of the strategy.